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| 13. ABSTRACT (Maximum 200 words)<br>Recent work from our laboratory demonstrated that carbohydrate supplementation (CHOS) during exercise improved prolonged time-trial (TT) performance of sea-level residents (SLR) living at 4300 m while they were in daily negative energy balance (-1250 kcal·day <sup>-1</sup> ; Fulco et al. J.Appl.Physiol. 2005). The purposes of the current study were to determine during initial exposure to 4300 m: 1) whether CHOS also improves TT performance of moderate altitude residents (MAR) who are in energy balance and 2) if acclimatization to moderate elevations benefits TT performance. Fifteen Air Force Academy (AFA) active duty members (age: 30 ± 1 yrs; mean ± SE) who had been living at ~2000 m for 21 ± 3 months performed a maximal effort 720 kJ cycle TT at the AFA and at Pikes Peak (PP), CO, (4300 m) on days 1 (PP1) and 3 (PP3). Daily energy intake and expenditure were maintained similarly at the AFA and PP. At the start of the TTs at PP, and then every 15 min thereafter, 9 subjects drank a 10% CHO solution (0.175 g·kg <sup>-1</sup> body weight) and 6 subjects drank a placebo (PLA) solution. All subjects were allowed to freely adjust the power output of the cycle ergometer and drank water ad libitum. Performance time did not differ between groups on PP1 (CHOS vs. PLA; 101±8 vs. 116±10 min) or PP3 (95±8 vs. 107±12 min). For both groups, cycle times on PP1 and PP3 were longer compared to the AFA (P<0.01) and were improved from PP1 to PP3 (P<0.05). Exercise intensity (i.e., % peak oxygen uptake) was maintained similarly at ~62% during the TTs at the AFA and PP. Blood glucose was 1.5 to 2.0 mmol·L <sup>-1</sup> higher for CHOS vs. PLA (P<0.01). It was concluded that CHOS provided no TT performance benefit for MAR at 4300 m when energy balance was maintained. However, the decrements in TT performance and exercise intensity were attenuated at 4300 m in MAR compared to those of SLR as a result of acclimatization attained while living for nearly 2 years at ~2000 m. |  |   |   |  |
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## Carbohydrate Supplementation and Endurance Performance of Moderate Altitude Residents at 4300 m

### Abstract

Recent work from our laboratory demonstrated that carbohydrate supplementation (CHOS) during exercise improved prolonged time-trial (TT) performance of sea-level residents (SLR) living at 4300 m while they were in daily negative energy balance ( $-1250 \text{ kcal} \cdot \text{day}^{-1}$ ; [9]). The purposes of the current study were to determine during initial exposure to 4300 m: 1) whether CHOS also improves TT performance of moderate altitude residents (MAR) who are in energy balance and 2) if acclimatization to moderate elevations benefits TT performance. Fifteen Air Force Academy (AFA) active duty members (age:  $30 \pm 1$  yrs; mean  $\pm$  SE), who had been living at  $\sim 2000$  m for  $21 \pm 3$  months performed a maximal-effort 720-kJ cycle TT at the AFA and at pikes peak (PP), CO, (4300 m) on days 1 (PP1) and 3 (PP3). Daily energy intake and expenditure were maintained similarly at the AFA and PP. At the start of the TTs at PP, and then every 15 min thereafter, 9 subjects drank a 10% CHO solution ( $0.175 \text{ g} \cdot \text{kg}^{-1}$  body weight) and 6 subjects drank a placebo (PLA) solution. All

subjects were allowed to freely adjust the power output of the cycle ergometer and drank water ad libitum. Performance time did not differ between groups on PP1 (CHOS vs. PLA;  $101 \pm 8$  vs.  $116 \pm 10$  min) or PP3 ( $95 \pm 8$  vs.  $107 \pm 12$  min). For both groups, cycle times on PP1 and PP3 were longer compared to the AFA ( $p < 0.01$ ) and were improved from PP1 to PP3 ( $p < 0.05$ ). Exercise intensity (i.e., %peak oxygen uptake) was maintained similarly at  $\sim 62\%$  during the TTs at the AFA and PP. Blood glucose was  $1.5$  to  $2.0 \text{ mmol} \cdot \text{L}^{-1}$  higher for CHOS vs. PLA ( $p < 0.01$ ). It was concluded that CHOS provided no TT performance benefit for MAR at 4300 m when energy balance was maintained. However, the decrements in TT performance and exercise intensity were attenuated at 4300 m in MAR compared to those of SLR as a result of acclimatization attained while living for nearly 2 years at  $\sim 2000$  m.

### Key words

Exercise performance · acclimatization · altitude · time trial

### Introduction

Peak oxygen uptake of sea-level residents (SLR) progressively decreases as elevation increases [11]. As a result, the duration of endurance tasks requiring that a fixed amount of work be completed as quickly as possible (e.g., a prolonged time-trial, TT) is

lengthened at altitude compared to sea level [9,11]. It was recently demonstrated that carbohydrate supplementation (CHOS) during exercise partly offsets the large TT performance decrement of SLR, who were living for 10 days at 4300 m while in negative energy balance (i.e.,  $-1250 \text{ kcal} \cdot \text{day}^{-1}$ ) [9]. Performance on the 3rd day at altitude compared to that at sea level was reduced

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by 73% for a placebo group, but only by 46% for the fitness-matched CHOS group. From the 3rd to the 10th day at altitude, TT performance improved for the placebo group but not the CHOS group; yet performance for the CHOS group was still 9% better than that of the placebo group. These results suggested that TT performance for the CHOS group may have been optimized and that it was influenced more by CHOS than by the salutary physiological effects associated with the first 10 days of altitude acclimatization.

While these results clearly indicated that CHOS improves performance of SLR at 4300 m, it was uncertain whether part of the between-group difference in TT performance was attributable to CHOS compensating for the reduction in endogenous CHO stores that resulted from daily negative energy balance. Moreover, it has long been known that individuals living for extended periods of time at given moderate to high elevations (e.g., 2200 to 4300 m) gradually acclimatize to their resident altitude, with a major outcome being improved endurance performance relative to their initial exposure [6,9–11]. The implication being that moderate altitude acclimatization may attenuate or even mask the impact of CHOS during a TT.

Because of the complex interactions between CHOS, negative energy balance, and altitude acclimatization [9], it was uncertain whether CHOS would improve TT performance similarly for acclimatized moderate altitude residents in energy balance as it did for unacclimatized SLR in negative energy balance during exposure to 4300 m. It also was not clear to what extent acclimatization acquired while living at a moderate elevation (e.g., 1800 to 2200 m) would modify TT performance during initial exposure to 4300 m compared to that of SLR.

The purposes of this study, therefore, were to determine during initial exposure to 4300 m: 1) whether CHOS improves TT performance of moderate altitude residents who are in energy balance and 2) the extent that acclimatization to moderate elevations benefits TT performance.

## Methods

### Subjects

Ten men and nine women who were active duty military personnel working at the Air Force Academy (AFA), Colorado Springs, CO volunteered to participate. All had been living in the Colorado Springs metropolitan area (1800 to 2200 m) for  $21 \pm 3$  months (range: 5 to 46 months, median: 20 months) prior to the start of the study. In addition, none of the subjects had lived at an elevation less than 1524 m or more than 2600 m for more than six days for at least 3 months prior to the start of the study. They also were: nonsmokers, participated in regular physical activity, passed their most recent standardized AFA physical fitness test battery (e.g., 1.5-mile run for time, maximum number of push-ups and sit-ups in 1 min, etc.), and not pregnant. All provided verbal and written consents after being fully informed of the nature of the study and its possible risks and benefits. The study was approved by the institutional review boards of the United States Army Research Institute of Environmental Medicine (USARIEM), the AFA, and The College of William and Mary.

### Study design overview

Subjects reported on three separate days to the Human Performance Laboratory at the AFA (594 mmHg, 2200 m) and then for 3 consecutive days at the USARIEM High Altitude Research Laboratory at the summit of pikes peak (PP, 458 mmHg, 4300 m). At least one week separated the AFA and PP test phases for each subject, and the same equipment was used during each phase.

Subjects performed a cycle ergometer peak oxygen uptake ( $\dot{V}O_{2peak}$ ) test on one of the three days, and a cycle ergometer endurance test on each of the other two days of each phase (i.e., at the AFA and PP). Thus, for the entire study, each subject performed a total of two  $\dot{V}O_{2peak}$  tests and four endurance tests. Subjects were driven by automobile from the AFA to the summit of PP (day 1, PP1) and an endurance test commenced two hours after arrival. At PP on day 2 (PP2) and on day 3 (PP3), a  $\dot{V}O_{2peak}$  test and another endurance test, respectively, were conducted.

Subjects were allowed to eat *ad libitum* throughout the entire study, but were told to fast for a minimum of 12 hr prior to all exercise test sessions. While at PP, they were strongly encouraged to replicate the caloric composition and volume to what they typically ate at the AFA (requested foods were provided). All food consumed at PP was monitored and recorded. In addition, while at the AFA, they were instructed to maintain their normal exercise conditioning routine. While living on PP, the subjects remained physically active by participating in mandatory supervised activities.

### Measurements

#### Cycle ergometer exercise tests

Electromagnetically braked cycle ergometers (Lode Co., Excalibur Sport, The Netherlands) were used to assess  $\dot{V}O_{2peak}$  and endurance exercise performance at the AFA and PP as previously described [9].  $\dot{V}O_{2peak}$  tests consisted of incremental progressive exercise stages to volitional exhaustion while the endurance tests consisted of two distinct segments: a steady-state exercise segment followed by a prolonged, self-paced maximal effort TT performance segment. The steady-state exercise segment was used for warm-up and to assure that the physiological responses during exercise while fasting were similar for both groups; the TT segment was used to assess performance changes due to CHO supplementation and acclimatization. Throughout all endurance tests, water was provided *ad libitum*.

During steady-state exercise, subjects pedaled for 5 min at 50 watts (W). They then completed two consecutive 20-min exercise bouts at  $46 \pm 3\%$  and  $59 \pm 3\%$  of their altitude-specific  $\dot{V}O_{2peak}$ . Having steady-state light and moderate work rates allowed assessment of physiological responses (blood values, heart rate, SaO<sub>2</sub>, ventilation, etc) at the same absolute (watts) and relative ( $\% \dot{V}O_{2peak}$ ) exercise intensities at the AFA to PP, and of acclimatization from PP1 to PP3. After a 5-min rest period, they then began the TT performance segment and were required to complete 720 kJ of total work as fast as possible. Subjects were allowed to alter pedaling speed and to adjust power output by any desired W increment at any time during cycling. This type of performance test was selected because of its high test-retest reproducibility and low coefficient of variance [9,12]. Subjects were provided real-time feedback (via computer screen graphics) of

total work performed and total work remaining but were not informed of their TT performance durations.

All four of the endurance tests were conducted using the same protocol. The only exception was that for the two, non-supplemented endurance tests at the AFA, blood samples were not drawn and, in addition to water provided *ad libitum*, water was offered at the exact volume, times, and frequency that the CHO supplement or placebo would be offered during the TT performance tests conducted on PP1 and PP3, respectively. Carbohydrate supplementation or placebo was provided only during the TT performance tests at PP.

#### Carbohydrate and placebo group assignment

The subjects were divided into either a placebo ( $n=9$ ) or CHOS ( $n=10$ ) group by a staff member not directly involved with any exercise testing such that there would be no differences ( $p>0.10$ ) in age, body weight, height, gender,  $\dot{V}O_{2peak}$ , and faster time needed to complete the two TTs at the AFA. However, midway into the AFA phase one woman (placebo) and one man (placebo) withdrew without completing all of the testing for personal reasons unrelated to the study. Of the remaining 17 subjects who ascended PP, one woman (CHOS) was withdrawn within six hours because of severe acute mountain sickness. Another woman (placebo) was unable to complete the first two days of exercise testing due to a hamstring injury. Therefore, all of the reported data are based on the remaining six subjects in the placebo group (4 men, 2 women) and nine subjects in the CHOS group (5 men, 4 women). Despite the loss of four subjects, the physical characteristics of the subjects between groups remained similar (Table 1).

The CHO supplement was a previously tested and highly acceptable [9,14] tropical punch or lemon-lime flavored (volunteer's choice) blend of maltodextrin (mass·volume<sup>-1</sup>, 9%), glucose (2%), and fructose (1%) (Ergo Drink, U.S. Army Soldier Systems Command, Natick, MA). Each powdered serving was reconstituted with water to a 10% CHO solution. At PP, at the start of the TT performance segment and every 15 min thereafter until completion, subjects consumed either 0.175 g·kg<sup>-1</sup> body weight (e.g., 80 kg bw = 14 g CHO and 140 ml·serving<sup>-1</sup>) of reconstituted Ergo Drink or an equal volume of indistinguishable placebo having no nutritive value. The study was conducted in a double-blind manner.

#### Blood measures

Venous blood samples were obtained via catheter for glucose, lactate, hemoglobin, and hematocrit (i-Stat, Abbott Diagnostics, Abbott Park, IL, USA) at rest. Hemoglobin and hematocrit were utilized to estimate potential changes in plasma volume from the AFA to PP [8]. The measurement sensitivities and inter- and intra-day variances (CV%) are 0.01 mmol·L<sup>-1</sup> (<2%) for glucose and lactate, 0.1 g·dL<sup>-1</sup> (<1.3%) for Hb, and 0.1 units (<1.4%) for Hct. Venous blood samples also were obtained via catheter for glucose and lactate after 15 min of cycling during each 20-min steady-state power output, and then at the completion of TT exercise. Volume of blood withdrawn for each blood sample was less than 4 ml. The total volume of blood withdrawn at PP was less than 32 ml.

Table 1 Physical characteristics of the placebo and carbohydrate groups

| Group | Age (yrs) | Weight (kgs) | Height (cm) | $\dot{V}O_{2peak}$ (ml·kg <sup>-1</sup> ·min <sup>-1</sup> ) | TT Time (min) |
|-------|-----------|--------------|-------------|--|---------------|
| PLA   | 30.7±2    | 71.8±3       | 171.7±4     | 40.2±3   | 92.7±8        |
| CHOS  | 30.0±1    | 69.2±3       | 176.4±3     | 43.4±3   | 85.1±8        |

Values are means ± SE; PLA = placebo group; CHOS = carbohydrate-supplemented group

#### Other measures

During all cycle exercise tests, heart rate (HR, heart rate monitor, Polar Corp., Hempstead, NY, USA), oxygen saturation (SaO<sub>2</sub>, non-invasive finger pulse oximeter, Nonin 8600, Plymouth, MN, USA), and ratings of perceived exertion (RPE, 6 to 20 Borg Scale [2]) were collected every two min. Oxygen uptake (True Max 2400 metabolic cart, ParvoMedics, Salt Lake City, UT, USA) was continuously collected during the  $\dot{V}O_{2peak}$  test, and at rest, and within the 10th to 15th min at 46%  $\dot{V}O_{2peak}$  and 59%  $\dot{V}O_{2peak}$ , respectively, during steady-state exercise during the endurance tests.

#### Comparisons to previous studies

Since the methodology, equipment, and staff employed in the present study were identical to a recent study of unacclimatized SLR who lived at PP for 10 days [9], the exercise performance results of both studies were compared. The data obtained in the present study also were compared to published data of sea-level, conditioned individuals who were acclimatized to similar elevations (~2200 m and 4300 m) for approximately 10 days prior to sporting events that lasted 1 to 3 hr [11].

#### Statistics

A two-factor (days×group) analysis of variance with repeated measures on one factor (days) was utilized for performance, physiological, and blood value comparisons. Post-hoc analyses (Neuman-Keuls) were performed when appropriate. Independent t-tests were used to compare specific characteristics (e.g., age, height) between groups. Regression analyses were used to determine the relationship between  $\dot{V}O_{2peak}$  and TT performance at the AFA and PP. Statistical significance was accepted when  $p\leq 0.05$ . All values are expressed as means ± SE unless otherwise indicated.

#### Results

There were no between-group differences in total Kcals, carbohydrate, fat, or protein intakes for any of the three days at pikes peak as indicated in Table 2.

#### Peak oxygen uptake and endurance tests

##### Peak oxygen uptake

From the AFA to PP,  $\dot{V}O_{2peak}$  declined by 13±1% (42.1±2 to 36.6±2 ml·min<sup>-1</sup>·kg<sup>-1</sup>,  $p<0.01$ ). There also were declines in HR<sub>peak</sub> (180±2 to 170±3 beats·min<sup>-1</sup>,  $p<0.01$ ) and SaO<sub>2peak</sub> (92±1 to 80±1%,  $p<0.01$ ).



**Table 2** Dietary intakes of the placebo and carbohydrate groups at pikes peak

|       | Group   | kcal (total) | CHO (g)  | Fat (g) | Protein (g) |
|-------|---------|--------------|----------|---------|-------------|
| Day 1 | placebo | 1731 ± 412   | 205 ± 39 | 66 ± 22 | 79 ± 18     |
|       | CHO     | 1813 ± 192   | 223 ± 30 | 61 ± 8  | 93 ± 11     |
| Day 2 | placebo | 2240 ± 312   | 303 ± 65 | 69 ± 12 | 102 ± 12    |
|       | CHO     | 2252 ± 230   | 286 ± 26 | 79 ± 9  | 99 ± 15     |
| Day 3 | placebo | 2496 ± 275   | 293 ± 46 | 99 ± 16 | 109 ± 11    |
|       | CHO     | 2415 ± 253   | 332 ± 46 | 71 ± 6  | 113 ± 15    |

Values are means ± SE. Note: day 1 was a shortened "eating" day due to travel and pre-exercise fasting

### Steady-state exercise segment

There were no statistical differences between the placebo and CHOS groups at rest or during either 20-min steady-state exercise segment of the endurance test at PP1 or PP3 for power output, %VO<sub>2peak</sub>, HR, %SaO<sub>2</sub>, RPE, glucose, or lactate.

### Time-trial performance segment

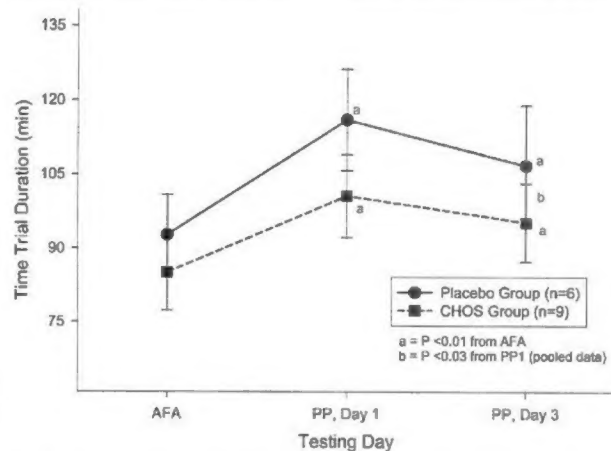
Time-trial duration did not differ statistically between the placebo and CHOS groups at PP1 (116 ± 10 vs. 101 ± 8 min) or PP3 (107 ± 12 vs. 95 ± 8 min). Post-hoc analyses indicate that there was an ~42% chance of a type II error (β). For each of the groups, there was no difference from PP3 compared to PP1 (Fig. 1).

During the TTs at PP, there were no differences between the placebo and CHOS groups in absolute (watts) or relative (%Watts<sub>peak</sub>) values for power output, %VO<sub>2peak</sub>, %SaO<sub>2</sub>, RPE, or in absolute (beats·min<sup>-1</sup>) or relative (%HR<sub>peak</sub>) values for HR.

Resting glucose level did not differ between groups at rest, or for the placebo group from rest to the end of the TT. As expected, glucose level for the CHOS group was nearly 40% higher than for the placebo group (6.77 ± 0.3 mmol·L<sup>-1</sup> vs. 4.86 ± 0.3 mmol·L<sup>-1</sup>; p < 0.01) at the end of the TTs at PP. Post-TT lactate values were similarly higher for both groups at the end of exercise compared to rest, and were higher on PP3 than on PP1 (p < 0.05). There was no between-group difference in resting plasma volume change nor was there a difference for either group from the AFA to PP.

Because there were no between-group differences due to supplementation (other than the expected higher glucose level for the CHOS group) the TT performance data of the two groups were pooled (i.e., placebo + CHOS groups) and are presented in Table 3.

The pooled data indicate that the TT duration on PP3 improved over that on PP1 (p < 0.05), with the TT duration being longer on each day at PP compared to the AFA (p < 0.01). Self-selected power output was reduced on PP1 compared to the AFA (p < 0.01), and then increased on PP3 to a level that did not differ significantly from the AFA. %Watts<sub>peak</sub> used during the TTs did not differ among test days. In contrast, the %VO<sub>2peak</sub> used during the TT was higher on both days at PP compared to the AFA (p < 0.01), and was higher on PP3 than on PP1 (p < 0.05). SaO<sub>2</sub> was lower for both PP test days compared to the AFA (p < 0.01),



**Fig. 1** Time-trial performance at the Air Force Academy and pikes peak. There were no performance differences between the placebo group (filled circles) and the CHOS group (filled squares) on any of the test days. Duration of the time trial (pooled data) was longer at pikes peak on day 1 (22%) and day 3 (14%) compared to the Air Force Academy (p < 0.01).

**Table 3** Time-trial exercise values for all subjects at the AFA and PP

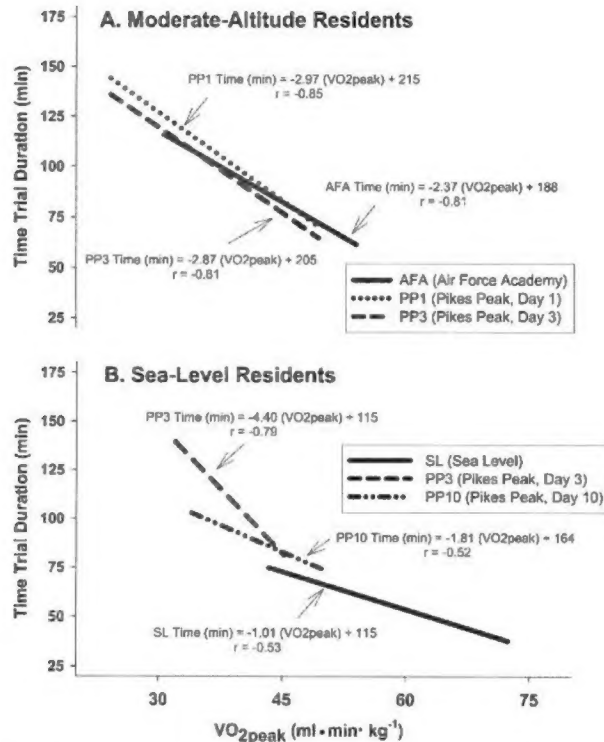
| Measure:                        | AFA        | PP1                     | PP3                     |
|---------------------------------|------------|-------------------------|-------------------------|
| TT duration                     | 88 ± 3     | 107 ± 3 <sup>a</sup>    | 100 ± 3 <sup>a,b</sup>  |
| Watts (absolute load)           | 144 ± 13   | 122 ± 10 <sup>a</sup>   | 134 ± 12 <sup>b</sup>   |
| Watts (%Watts <sub>peak</sub> ) | 54.4 ± 3   | 50.0 ± 3                | 59.0 ± 3                |
| %VO <sub>2peak</sub>            | 59.9 ± 3   | 65.4 ± 2 <sup>a</sup>   | 70.0 ± 3 <sup>a,b</sup> |
| SaO <sub>2</sub> (%)            | 92.1 ± 1   | 79.2 ± 1 <sup>a</sup>   | 80.1 ± 1 <sup>a</sup>   |
| RPE                             | 14.6 ± 0.4 | 15.4 ± 0.3 <sup>a</sup> | 14.8 ± 0.4 <sup>b</sup> |
| HR (beats·min <sup>-1</sup> )   | 157 ± 5    | 155 ± 3                 | 153 ± 4                 |
| HR (%HR <sub>peak</sub> )       | 87.0 ± 2   | 91.3 ± 1 <sup>a</sup>   | 89.9 ± 1                |

Values are means ± SE, AFA = Air Force Academy; PP1 or PP3 = pikes peak, day 1 or day 3; VO<sub>2peak</sub> = peak oxygen uptake; SaO<sub>2</sub> = arterial oxygen saturation; RPE = ratings of perceived exertion; HR = heart rate; <sup>a</sup> p < 0.01 from AFA, <sup>b</sup> p < 0.05 from PP1

with no difference between PP days. RPE increased from the AFA to PP1 (p < 0.01), and then decreased to the same level on PP3 as at the AFA. HR was similar among test days at approximately 155 beats·min<sup>-1</sup>. %HR<sub>peak</sub> used was higher on PP1 compared to the AFA, and tended to decrease from PP1 to PP3 (p = 0.063).

### Performance comparisons to our previous study

Regression lines in Fig. 2 depict the inverse relationships between VO<sub>2peak</sub> and TT performances of acclimatized moderate altitude residents (MAR) from the current study (panel A) and unacclimatized SLR from our previous study ([9]; panel B). Most noteworthy for MAR (panel A) are the similarities in slopes, intercepts, and correlation coefficients among all test days. The leftward shift for the PP lines relative to the AFA line is due to the sustained reduction in VO<sub>2peak</sub> from the AFA to PP. In addition, the PP1 line is slightly above the PP3 line; a difference resulting



**Fig. 2A and B** Regression lines depict the relationship of  $\dot{V}O_{2peak}$  and time-trial duration for acclimatized MAR in current study (A) and unacclimatized SLR of a previous study (B) [9] exposed to 4300 m. In panel A, time-trial performance data were collected at the Air Force Academy and on days 1 and 3 at pikes peak. In panel B, the identical time-trial performance tests were conducted at sea level, and on days 3 and 10 at pikes peak. Note that a dashed line represents the 3rd day at pikes peak for both studies. For MAR, but not for SLR, there was little change in the relationship between  $\dot{V}O_{2peak}$  and TT performance when exposed to 4300 m.

from the subjects cycling at a reduced power output – and thereby a longer TT duration – on PP1 compared to PP3. The similarity of the magnitudes of the impairment for  $\dot{V}O_{2peak}$  ( $-13 \pm 1\%$ ) and TT performance on PP1 ( $22\% \pm 3\%$ ,  $p < 0.01$ ) and PP3 ( $14 \pm 3\%$ ,  $p < 0.01$ ) suggest that for MAR exposed to 4300 m, the TT performance impairments result primarily from the reduction in  $\dot{V}O_{2peak}$ .

For SLR (panel B), the spatial orientation of the lines relative to one another is quite different from what is depicted for MAR. Compared to the SL line, the PP3 line has a slope that is more than 4X as steep ( $p < 0.01$ ). From PP3 to PP10, the slope decreased by more than half ( $p < 0.05$ ) because of a 25% improvement in TT performance with no improvement in  $\dot{V}O_{2peak}$ . That is, for SLR exposed to 4300 m, a 26% reduction in  $\dot{V}O_{2peak}$  resulted in TT performance reductions of  $73 \pm 13\%$  on PP3 and  $49 \pm 9\%$  on PP10 [9], suggesting that factor(s) other than only the reduction in  $\dot{V}O_{2peak}$  are responsible for the TT performance impairments at 4300 m for SLR.

To determine if a lack of acclimatization of the SLR relative to MAR could be implicated as a factor,  $SAO_2$  and the three indices of exercise intensity collected during the TT performance tests

**Table 4** Indices of time trial (TT) exercise intensity and acclimatization

|                           | SL or AFA baseline | PP1                | PP3                     | PP10            |
|---------------------------|--------------------|--------------------|-------------------------|-----------------|
| $\% \dot{V}O_{2peak}$ SLR | $60 \pm 4$         |                    | $57 \pm 4$              | $66 \pm 3^*$    |
| $\% \dot{V}O_{2peak}$ MAR | $57 \pm 4$         | $60 \pm 3$         | $65 \pm 6$              |                 |
| $\% Watts_{peak}$ SLR     | $58 \pm 4$         |                    | $44 \pm 4^*$            | $55 \pm 3$      |
| $\% Watts_{peak}$ MAR     | $50 \pm 5$         | $51 \pm 5$         | $56 \pm 7$              |                 |
| $\% HR_{peak}$ SLR        | $82 \pm 3$         |                    | $77 \pm 3$              | $86 \pm 3^{**}$ |
| $\% HR_{peak}$ MAR        | $86 \pm 4$         | $89 \pm 1^\dagger$ | $88 \pm 2^\dagger$      |                 |
| $SAO_2$ (%) SLR           | $96 \pm 1$         |                    | $75 \pm 3^*$            | $82 \pm 1^{**}$ |
| $SAO_2$ (%) MAR           | $93 \pm 1$         | $80 \pm 1^*$       | $81 \pm 1^{* \ddagger}$ |                 |

Values are means  $\pm$  SE. SLR = sea level residents;  $n = 8$ , placebo group, from reference [9]; MAR = moderate altitude residents, present study; PP1, PP3, or PP10 = pikes peak, day 1, day 3, or day 10; HR = heart rate (beats/min); \*  $p < 0.05$  from associated SL or AFA baseline; \*\*  $p < 0.05$  from day 3;  $^\dagger p < 0.01$  from  $\% HR_{peak}$  SLR, day 3;  $^\ddagger p < 0.01$  from  $\% SAO_2$  SLR, day 3

for MAR and SLR were compared:  $\% \dot{V}O_{2peak}$ ,  $\% Watts_{peak}$ , and  $\% HR_{peak}$ . There were no differences in  $SAO_2$  or in any index of exercise intensity between the MAR and SLR at their resident altitudes prior to being exposed to PP (Table 4). However, each intensity index was decreased or tended to decrease for SLR on PP3 before recovering towards their SL baseline value on PP10. In contrast, the MAR did not experience a decline in any intensity index on either day at PP compared to AFA baseline. On PP3 – the only directly comparable day between the MAR of the present study and the SLR of the previous study [9] – the MAR were able to exercise at a higher intensity and had a higher  $SAO_2$  (a primary indicator of altitude acclimatization). Note that the value for  $SAO_2$  for the MAR within hours of exposure at PP was similar to that of the SLR after their 10 days at PP.

## Discussion

One major finding from the current study is that CHOS did not improve TT performance for MAR at 4300 m. The lack of improvement is in striking contrast to our previous study that reported that CHOS was beneficial to SLR exposed to the identical elevation and TT performance procedures [9]. However, major experimental design differences between studies may explain the disparity in TT performance outcome.

In the previous study of SLR [9], there was a significant reduction in body weight ( $\sim 2.5$  kg) at altitude that was induced by increased energy expenditure ( $\sim 500$  kcal  $\cdot$  day $^{-1}$ ) and decreased energy intake ( $750$  kcal  $\cdot$  day $^{-1}$ ) that, in turn, likely reduced muscle glycogen concentration to less than optimal levels prior to the start of the TTs at PP. In the current study of MAR, body weight [15], diet, and activity levels at PP were not altered from those at the AFA suggesting that muscle glycogen concentration also was similar and replete prior to the start of the TTs at PP. There also were no differences in dietary intake or composition between groups at PP. Moreover, subjects from the placebo group

of both studies exercised during the TT at a similar  $\% \dot{V}O_{2peak}$  for nearly identical durations. These observations along with the fact that the rate of muscle glycogen utilization during prolonged exercise is directly related to  $\% \dot{V}O_{2peak}$  [7], imply that muscle glycogen in the current study was at a higher concentration at the start of exercise and was maintained at a higher level throughout the TT. In such a scenario, there would be less reliance on blood glucose for sustaining total CHO oxidation [7] and exercise intensity [5] during the TT. This interpretation is consistent with our current findings of no TT performance difference between groups despite a large difference in blood glucose levels.

Endurance performance is impaired at altitude compared to sea level, with the largest decrement occurring during initial exposure [11]. It is well established that acclimatization resulting from living for weeks to years at moderate to high elevations greatly improves endurance performance at the resident altitude [11,13,16]. Contributing to the improved performance is a near normalization of arterial oxygen content resulting from ventilatory acclimatization and hemoconcentration [16,17]. In the present study,  $SAO_2$  during the TT in the first few hours of exposure to 4300 m was reduced from the AFA; but was already at a level (~80%) that is typically demonstrated by SLR exercising at the same intensity only after 10 or more days of residence at the same elevation [1]. In addition, there was no reduction in plasma volume at PP compared to the AFA [15]. This finding is in contrast to a 7 to 14% reduction typically reported for SLR exposed to 4300 m for a similar exposure duration [17] and suggests that much of the plasma volume adjustment had already occurred as a result of acclimatization acquired while living at moderate altitude. Therefore, a second major finding of the current study was that acclimatization attained while living for an average of nearly two years at a moderate elevation greatly preserved and benefited TT performance during the first few days of exposure to 4300 m.

To quantitate the advantage of acclimatization acquired while living at 2200 m on endurance performance during exposure to 4300 m elevation, results of the present study were compared to compiled athletic event data of previous studies that had similar durations [11] (see Fig. 3). To determine the difference in performance impairments for events lasting 1 to 3 hours, comparisons were made between a group of SLR who lived for ~10 days at 2200 m before competing at 2200 m and another group of SLR who lived ~10 days at 4300 m before competing at 4300 m. The impairment in performance between 2200 m to 4300 m for the SLR was estimated as 45% [11]. In the present study, compared to performance at the AFA, there was a 22% impairment on PP1 that was improved to 14% on PP3. In other words, the performance impairment for MAR is estimated to be 50% to 70% less during the first few days at 4300 m compared to that of SLR who had been living at 2200 m and 4300 m for ~10 days.

## Conclusions

Two groups of subjects who had been living for 21 months at moderate elevations ranging from 1800 to 2200 m were rapidly transported to pikes peak (PP, 4300 m) where they lived for 3 days. On the 1st and 3rd days at PP, the effects of CHOS (10% sol-

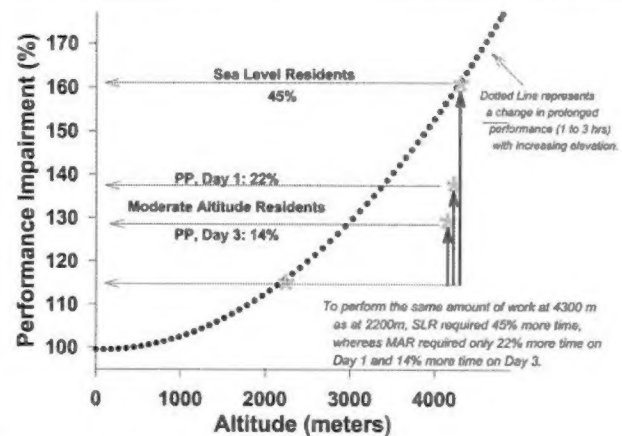


Fig. 3 Benefit of long-term acclimatization (~2 years) compared to short-term acclimatization (~10 days) to 2200 m on subsequent prolonged performance at 4300 m. Between 2200 m and 4300 m, there is a performance impairment of 45% for SLR but only 22% or less for MAR. Modified from Fulco et al. [11].

ution every 15 min) on TT performance were assessed. During the TT, blood levels of glucose and lactate, heart rate,  $SAO_2$ , and RPE were measured repeatedly. Carbohydrate supplementation raised blood glucose levels during the TT, yet both the CHOS and placebo groups had similar physiological responses, and there was no between-group difference in TT performance. We conclude that CHOS had little effect during exercise for MAR exposed to a higher elevation and who were not in negative energy balance. We also determined that living at moderate elevations provides sufficient acclimatization such that exercise intensity during the TTs at PP was well maintained compared to that at 2200 m. Moreover, prolonged exercise performance during the first 3 days of exposure to 4300 m for MAR was at least 50% better compared to previous reports of SLR similarly exposed to 4300 m.

## Disclaimers

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The investigators have adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 45 CFR part 46.

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